

A delayed coincidence measurement of the 2.9×10^{-10} sec. half-life of the 279 keV first excited state in Thallium 203

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With 2 figures in the text

ABSTRACT

The half-life of the 279 keV first excited level in Tl^{203} has been remeasured by the delayed coincidence technique. An electron-electron coincidence spectrometer was used for the energy resolution. A half-life of $(2.9 \pm 0.2) \cdot 10^{-10}$ sec. has been obtained, in good agreement with earlier results from delayed coincidences, nuclear resonance- and Coulomb excitation measurements.

The reduced transition probability for the $E2$ transition and the matrix element for the $M1$ transition were calculated and compared with those obtained from the single particle model.

Introduction

The life-time of the 279 keV first excited state in Tl^{203} has been measured by several different methods, namely, delayed coincidence technique [1, 2, 3, 4], resonance fluorescence scattering [5] and Coulomb excitation [6, 7]. The $d_{3/2} \rightarrow s_{1/2}$ transition to the ground state is a mixture of $E2$ and $M1$. The $E2/M1$ mixing ratio has been accurately determined by means of directional polarization experiments in Coulomb excitation [6], and is in reasonable agreement with a value obtained from $K/L_I + L_{II}/L_{III}$ ratios [8]. The mixing ratio has been recalculated using the most recent theoretical conversion coefficients [9, 10]. Furthermore, there exist several precision measurements of the conversion coefficient (cf. ref. [11] for a review of experimental values for these coefficients).

For these reasons Tl^{203} presents a rather unique possibility of comparing the three above mentioned independent methods for the measurement of short nuclear lifetimes. The lifetime of the nuclear level, as given in each of these cases, is:

Delayed coincidence measurement:

$$\tau = \text{centroid shift of delayed coincidence curve} \quad (1)$$

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Resonance fluorescence scattering [12]:

$$\tau_{\gamma} = \frac{\hbar}{\Gamma_1}$$

$$\sigma = g \frac{\lambda^2}{8\pi} \frac{\Gamma_1^2}{(E - E_0)^2 + (\Gamma/2)^2} \quad (2)$$

where σ is the absorption cross section. Γ is the total width of the excited level and Γ_1 the partial width, corresponding to the gamma transition rate. E and λ are the energy and wave length respectively of the exciting gamma ray. E_0 is the energy of the excited level and g is a statistical factor.

Coulomb excitation:

$$\sigma_{E\lambda} = C_{E\lambda} E^{\lambda-2} (E - \Delta E')^{\lambda-1} B(E\lambda) f_{E\lambda}(\eta_i \zeta)$$

where E and $\Delta E'$ are related to the energy of the bombarding particle and the excitation energy respectively, $C_{E\lambda}$ and $f_{E\lambda}(\eta_i \zeta)$ are functions given by Alder *et al.* [13].

A comparison between the three different methods serves as a critical check of the theories used to derive the expressions (1), (2) and (3).

Earlier experiments using the three methods mentioned have failed to give consistent values. Recent experiments [3], however, tend to show agreement. It was decided to remeasure the 279 keV lifetime of Tl^{203} by delayed coincidence technique and to employ the coincidence spectrometer method [14] in order to eliminate systematic errors due to energy dependent instrumental time delays.

The lifetime of the first excited state in Tl^{203} is also of an intrinsic interest being partly de-excited by means of an l -forbidden $M1$ transition. The l -forbidden transitions in odd Tl isotopes are at present subject to studies from various points of view at this institute in connection with theories developed by Arima, Horie and Sano [15] on the electromagnetic transition matrix elements and by Church and Weneser [16] on conversion matrix elements. Recently Kisslinger [17] has made a study of Tl^{203} combining the results of Arima *et al.* [15] with those found by Church and Weneser [16]. Finally the $E2$ transitions in Tl^{203} are of a certain interest from the Bardeen-model point of view being due to collective excitations of a nearly closed shell configuration.

Experimental

Hg^{203} was produced at Harwell by the process $\text{Hg}^{202}(n, \gamma)\text{Hg}^{203}$. The target material of Hg enriched by 90% Hg^{202} was irradiated over a period of three weeks in a flux of approximately 10^{14} neutrons $\text{cm}^{-2} \text{sec}^{-1}$. A specific activity of 30 mc/gm was obtained. The active material was then transformed into chloride and evaporated in vacuum onto an aluminium backing of 2 mg/cm^2 . This source was then covered by a thin layer of zapon ($15\text{--}20 \mu\text{g/cm}^2$) to prevent evaporation of the mercury in the spectrometer.

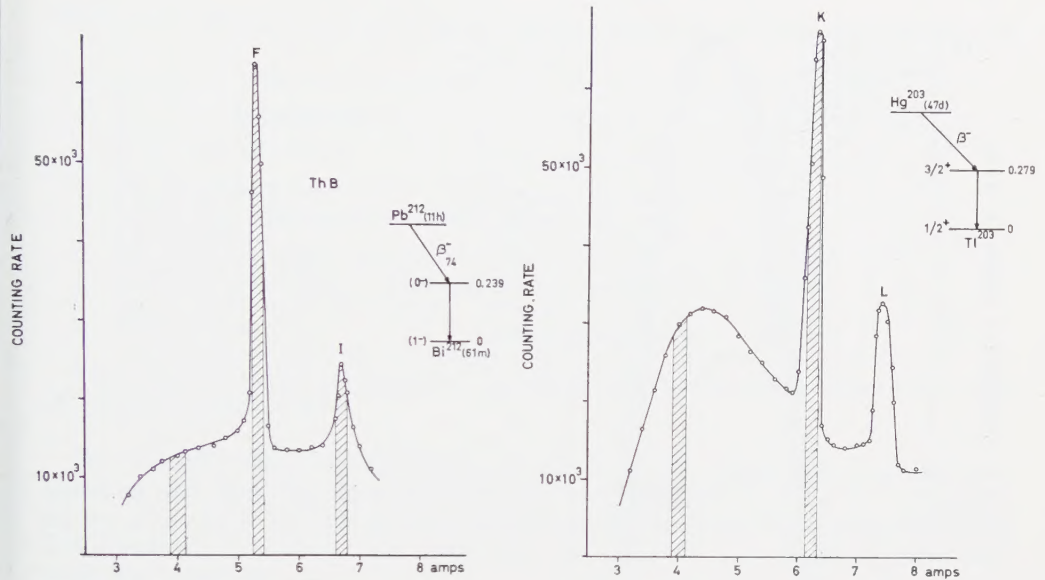


Fig. 1. Beta-spectra of Pb^{212} and Hg^{203} . The shadowed areas indicate the position of the spectrometer channels.

In the experiment we recorded coincidences between the beta-branch from the ground state of Hg^{203} feeding the 279 keV level in Tl^{203} and the K conversion electrons from the 279 keV transition.

The electrons were selected in the two halves of an electron-electron coincidence spectrometer [18]. Because of the simplicity of the decay scheme it was sufficient to adjust the spectrometer to a line width of 4 percent for the conversion electrons and 4 percent for the continuous beta-background. As detectors we used plastic scintillators and RCA 6810 photomultipliers. We used a coincidence circuit described by R. E. Bell [19] with a resolving time of 3 m μ s. A coincidence counting rate of 4 counts per second was obtained between the maximum of the beta-spectrum and the K -conversion electrons in Tl^{203} . The accidental coincidence counting rate was about 1% of the maximum coincidence counting rate. When a resolution curve with more than 1000 coincidences on the peak had been obtained, the Hg^{203} source was replaced by a Pb^{212} (ThB) source. One spectrometer focused the L -conversion electrons from the 239 keV transition while the setting of the other spectrometer remained the same as in the case of Hg^{203} . This spectrometer now focused part of the beta-branch feeding the 239 keV level in Bi^{212} . Another resolution curve was recorded in the same way but with the K -conversion electrons from the 239 keV transition focussed instead of the L -conversion electrons. As a result, three resolution curves were obtained.

Throughout the experiments all parameters were kept constant. The only difference between the Hg^{203} runs and the Pb^{212} runs is due to the slight readjustment (~ 12 percent) of the current in one spectrometer in order to focus the 279 keV line of Hg^{203} and the K and L lines in Pb^{212} respectively. The

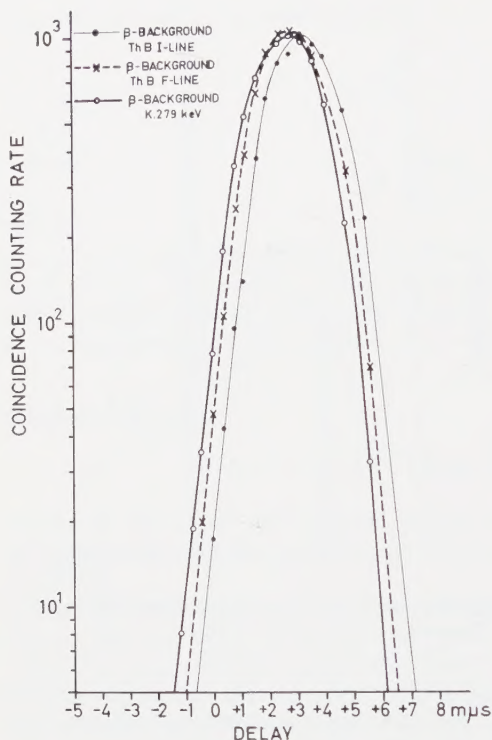


Fig. 2. Coincidence resolution curves between the beta-transitions at 90 keV and the ThB I-line, ThB F-line and the K-line of the 279 keV transition in Tl^{203} respectively.

instrumental time shifts introduced because of this readjustment were eliminated (including second order effects) by means of the interpolation procedure discussed in earlier publications [14, 20].

Taking the statistical errors into consideration the meanlife for the excited state was found to be $(4.1 \pm 0.3) \cdot 10^{-10}$ sec. The present results for the halflife $(2.9 \pm 0.2) \cdot 10^{-10}$ sec. is in agreement with the value $(2.9 \pm 0.3) \cdot 10^{-10}$ sec. earlier found by the delayed coincidence technique [3].

Results

Our above mentioned experimental result should be compared with the most recent measurements obtained by resonance scattering and Coulomb excitation. The comparison is shown in table 1, where we have

$$\alpha = 0.21 \pm 0.04 \quad \text{quoted from [8]}$$

$$\delta^2 = \frac{\lambda(E2)}{\lambda(M1)} = 2.25 \pm 0.25 \quad \text{quoted from [6].}$$

In our comparison we have excluded earlier less reliable experimental results found by resonance scattering and by delayed coincidence measurements [2]. It should also be mentioned that Alväger and Johanson [21] recently obtained a value $T_{1/2} = 2.2 \cdot 10^{-10}$ sec. by means of high frequency deflection [22].

Table 1. Comparison between different measurements of the lifetime of the 279 keV level in Tl^{203} .

Investigators	Method	$T_{1/2}^a$ in 10^{-10} sec	Ref.
R. Barloutaud <i>et al.</i>	Coulomb excitation	3.6 ± 1.2	7
F. K. McGowan and P. H. Stelson	Coulomb excitation	3.2 ± 0.4	6
F. R. Metzger	Nuclear resonance	2.7 ± 0.5	5
R. E. Azuma and G. M. Lewis	Delayed coincidences	2.1 ± 0.7	1
E. E. Berlovich and G. V. Dubinkin	Delayed coincidences	2.9 ± 0.3	3
G. T. Ewan and R. L. Graham	Delayed coincidences	2.5 ± 0.7	4
Present work	Delayed coincidences	2.9 ± 0.2	

^a The half-life has been calculated from the figures given by the authors using $\alpha = 0.21 \pm 0.04$ [8, 11] and $\delta^2 = 2.25 \pm 0.25$ [6].

We conclude that the discrepancy found in earlier experiments now has been removed and that the three methods all give consistent results. The agreement serves as a check of the theories underlying the analysis of resonance scattering and Coulomb excitation and may also be regarded as a check of the values used for α and δ^2 .

In table 2 we give the matrix element for the l -forbidden transition derived from the expression given by Arima, Horie and Sano [15]

$$\mathcal{M}^2 = \frac{2j+1}{0.419 \cdot 10^{13} \cdot E_\gamma^3 \cdot \tau_\gamma(M1)}$$

where $\mathcal{M}^2$ is expressed in nuclear magnetons, E_γ in MeV. j is the spin of the excited level. The reduced transition probability for the $E2$ is derived from the expression [23]

$$B(E2) = 81.4 (\Delta E)^{-5} \lambda_\gamma(E2)$$

where $B(E2)$ is expressed in units of $10^{-48} \text{ e}^2 \text{ cm}^4$ and ΔE in keV.

Table 2. Transition probabilities for $d_{3/2} - s_{1/2}$ transitions in Tl^{203} .

$M1$ transition		$E2$ transition	
Experimental matrix element for $M1$ in $n.m.$	0.026 ± 0.003	$B(E2)_{\text{exp}}$ in $10^{-48} \text{ e}^2 \text{ cm}^4$	0.065 ± 0.011
SPM matrix element for an allowed $M1$ transition in $n.m.$	26.8	$B(E2)_{\text{SPM}}$ in $10^{-48} \text{ e}^2 \text{ cm}^4$	0.0071
Retardation factor	1000 ± 110	Enhancement factor	9.2 ± 1.5
Arima, Horie and Sano's matrix element for an l -forbidden $M1$ -transition in $n.m.$	0.267	Surface tension according to weak coupling model in MeV	640 ± 110

We also give the corresponding matrix element for an (allowed) $M1$ transition according to the Single Particle Model as well as the retardation factor found in our experiment for the l -forbidden transition. In table 2 is given the theoretical value obtained for the retardation factor according to the theory of Arima, Horie and Sano [15]. A similar comparison is given for the $E2$ transition probability.

The enhancement factor obtained from the weak surface coupling model [21] corresponds to a surface tension of 640 ± 110 MeV. This figure is to be compared with values found for the neighbouring isotopes, i.e. for Pb^{206} 780 MeV [24] and Hg^{202} 170 MeV [13]. One should, of course, expect the surface tension of the Tl-core to lie between these extremes.

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REFERENCES

1. R. E. AZUMA and G. M. LEWIS, *Phil. Mag.* **46**, 1034 (1955).
2. H. DE WAARD, *Phys. Rev.* **99**, 1045 (1955).
3. E. E. BERLOVICH and G. V. DUBINKIN, *Soviet Physics JETP* **5**, 164 (1957).
4. G. T. EWAN and R. L. GRAHAM, Atomic Energy of Canada, Ltd, Chalk River, Ontario, Canada; private communication to ref. 5.
5. F. R. METZGER, *J. Franklin Inst.* **261**, 216 (1956).
6. F. K. MCGOWAN and P. H. STELSON, *Phys. Rev.* **109**, 901 (1958).
7. R. BARLOUTAUD *et al.*, *Physica* **22**, 1129 (1956).
8. C. NORDLING *et al.*, *Nuclear Physics* **1**, 326 (1956).
9. M. E. ROSE, *Internal Conversion Coefficients*, North Holland Publishing Co. (1958).
10. L. A. SLIV and I. M. BAND, *Coefficients of the Internal Conversion of Gamma Radiation*, Part I and II, Academy of Sciences of the U.S.S.R., Moscow, Leningrad (1956).
11. G. J. NIJGH *et al.*, *Nuclear Physics* **9**, 528 (1958-59).
12. J. D. JACHSON, *Can. J. Phys.* **33**, 575 (1955).
13. K. ALDER *et al.*, *Rev. Mod. Phys.* **28**, 432 (1956).
14. J. LINDSKOG *et al.*, to be published in *Nuclear Physics*.
15. A. ARIMA *et al.*, *Prog. Theor. Phys.* **17**, 567 (1957).
16. E. L. CHURCH and J. WENESER, *Phys. Rev.* **104**, 1382 (1956).
17. L. S. KISSLINGER, *Phys. Rev.* **114**, 292 (1959).
18. T. R. GERHOLM, *Rev. Sci. Instr.* **26**, 1069 (1955).
19. R. E. BELL *et al.*, *Can. J. Phys.* **30**, 35 (1952).
20. E. BASHANDY, to be published in *Nucl. Instr.*
21. B. JOHANSSON and T. ALVÄGER, private communication.
22. B. JOHANSSON and T. ALVÄGER, *Nucl. Instr.* **3**, 49 (1958).
23. A. BOHR and B. R. MOTTELSON, *Dan. Mat. Fys. Medd.* **27** nr 16 (1953).
24. W. W. TRUE and K. W. FORD, *Phys. Rev.* **109**, 1675 (1958).

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